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(54) **Adjustable booster for fluidized bed gasifiers.**

(57) A process for optimizing the ash separation and cooling operation of a fluidized bed gasifier which produces a mixture of ash and char from a carbonaceous material, comprising the steps of feeding the carbonaceous material to a gasifier at a first rate, discharging the mixture from the gasifier at a second rate approximately equal to a rate of introduction of ash contained in the carbonaceous material fed into the gasifier, maintaining the discharge temperature of the mixture below a temperature T, injecting a first gas at a first elevation within the gasifier, injecting a second gas at a second elevation which is above the first elevation to refluidize a portion of the mixture, measuring the ash content of the discharged mixture, and measuring sintering of ash of the discharged mixture; characterized by the further steps of

(1) raising the second gas injection elevation to increase the ash content of lowering the second gas injection elevation to reduce sintering of the discharged ash, and

(2) repeating the above process until both ash content and sintering of ash of the discharged mixture is acceptable.

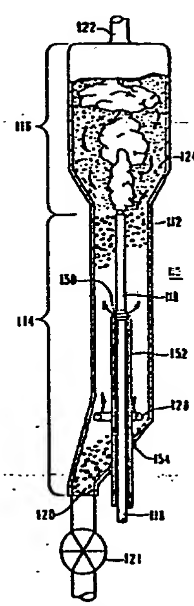

FIG. 2

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ADJUSTABLE BOOSTER FOR FLUIDIZED BED GASIFIERS

This invention relates to gasification of carbonaceous materials and more particularly to apparatus for separation and cooling of ash from fluidized bed gasifiers.

In reactors for the gasification of carbonaceous materials such as coal, a combustible product gas is produced as well as solid waste products such as agglomerated ash. In a typical fluidized bed gasifier, coal particles are pneumatically transported by gas into the hot gasifier (or reactor). Other process mediums such as steam, and a gaseous source of oxygen such as air or pure oxygen are injected, as well as perhaps a clean recycled product gas. This process results in fluidization of the coal particles in a bed above the nozzle. Further, the injection of coal and oxygen into the hot gasifier results in combustion of a portion of the coal and the heat thereby released maintains the temperature in the gasifier. As the non-combusted coal particles are heated, rapid evaporation, or devolatilization, of volatiles in the coal occurs. The average temperature within the vessel typically runs between 871°C and 1093°C or higher and this high temperature insures that the products of devolatilization, such as tars and oils, etc., are broken down, or cracked, and gasified to form methane, carbon monoxide and hydrogen. As the coal continues to heat, devolatilization is completed and

particles of coal become pieces predominantly of ungasified carbon or char. As this char circulates through the fluidized bed, the carbon in the char is gradually consumed by combustion and gasification, leaving ash-rich particles that have a high ash content. The ash-rich particles contain mineral compounds and eutectics that melt at temperatures of between 538°C to 1093°C and typically consist of compounds of any or all of S, Fe, Na, Al, K and Si, which compounds are typically denser than carbon compounds. These liquid compounds within the particles extrude through pores to the surfaces where they cause the particles to stick to each other, or agglomerate. In this way, ash agglomerates are formed that are larger and denser than the particles of char in the bed. As their density and size increase, the fluidized bed is unable to support them. Gradually, the density of the ash agglomerates becomes high enough that they can no longer be supported in the fluidized bed and the ash agglomerates defluidize into an ash annulus region of the vessel.

As an additional complication, the dynamics of the fluidized bed result in defluidization of substantial amounts of char particles into the ash annulus. Since the char particles contain significant quantities of carbon, loss of these char particles would result in significant process inefficiencies. Accordingly, it is desirable that the char and ash that defluidizes into the ash annulus be separated in such a manner that the char can be returned to the fluidized bed.

It is also desirable that the ash agglomerates which are ultimately removed from the vessel are at a sufficiently low

temperature that they can be handled without damage to equipment from the retained heat. Accordingly, it is desired that some cooling be performed on the ash agglomerates prior to discharge from the vessel.

One method of separating and cooling the ash is discussed in U.S. Patent No. 4,282,010 in the name of P. Cherish et al. Another method is set forth in U.S. Patent No. 4,309,194 in the name of L. A. Salvador et al. Still another method is set forth in pending U.S. Application Serial No. 518,338, identified by Attorney Docket No. W.E. 50,851. In all of these teachings, which are hereby incorporated by reference, agglomerated ash from the fluidized bed defluidizes into an elongated ash withdrawal section. It is a further characteristic of these references that separation of the agglomerated ash from smaller particles of char is accomplished by the addition in the elongated ash withdrawal section of an additional fluidizing gas.

The general region in which the fluidized bed ends and the agglomerated ash level begins is called the fluidynamic char-ash interface. In gasifiers in accordance with the above-named references, the elevation of the fluidynamic char-ash interface is assumed to be constant regardless of feed material, when it ideally may not be. This results in process and system considerations which could be eliminated if there were suitable means to respond to changes in the interface position while the gasifier was operating.

Any disruption of the fluidized bed within the gasifier such as a full loss of auxiliary power, loss of one or more of the process mediums, or an increase or decrease in pressure or temperature, is called an "upset" condition. During an upset

condition, ash continues to collect in the ash annulus. A critical consideration during an upset condition is the level of the ash within the annulus. As long as the ash level is below the top of the feed tube, recovery from an upset condition may be relatively easy. If the ash level covers the tip of the feed tube, the feed tube may become clogged or may simply be unable to fluidize the bed through the ash packed above the feed tube. In order to prevent full shutdown and cooldown of the gasifier, it is desirable to have a built-in time delay during which an operator can recover from such an upset condition. As a result, it is desirable to operate the gasifier in a normal operating mode with the ash level at an elevation which provides sufficient time delay to recover from most upset conditions. For a low-ash coal this level will be higher than for a high-ash coal.

With the above consideration, it would seem that a high ash withdrawal rate, leading to a low level in the ash annulus, would be desirable. On the contrary, such operation could result in withdrawal of ash at a higher temperature than normal. Since the additional fluidizing gas of the prior art cited above performs a cooling function, it is desirable to leave the ash in the annulus for a period of time to enhance its cooling. The conflicting considerations governing the ash level in the annulus can be seen from the above. Accordingly, being able to respond to this change in desired ash level, and therefore the char-ash interface, will result in the flexibility of the gasifier to more easily operate with different carbonaceous materials with different ash contents.

Thus the principal object of the present invention is to provide an apparatus which can be used in a convenient manner in a carbonaceous material gasifier which will allow optimum on-line positioning of the char-ash interface within a fluidized bed gasifier for a particular coal being used.

With this object in view, the present invention resides in a process for optimizing the ash separation and cooling operation of a fluidized bed gasifier which produces a mixture of ash and char from a carbonaceous material, comprising the steps of feeding the carbonaceous material to a gasifier at a first rate, discharging the mixture from the gasifier at a second rate approximately equal to a rate of introduction of ash contained in the carbonaceous material fed into the gasifier, maintaining the discharge temperature of the mixture below a temperature T, injecting a first gas at a first elevation within the gasifier, injecting a second gas at a second elevation which is above the first elevation to refluidize a portion of the mixture, measuring the ash content of the discharged mixture, and measuring sintering of ash of the discharged mixture; characterized by the further steps of

(1) raising the second gas injection elevation to increase the ash content or lowering the second gas injection elevation to reduce sintering of the discharged ash, and

(2) repeating the above process until both ash content and sintering of ash of the discharged mixture is acceptable.

The invention will become more readily apparent from the following description of a preferred embodiment thereof shown, by way of example only, in the accompanying drawings in which:

Figure 1 is a partial cross-sectional view in elevation of a fluidized bed gasification reactor in accordance with the state of the art;

Figure 2 is a partial cross-sectional view in elevation of a fluidized bed reactor in accordance with the invention; and

Figure 3 is a cross-sectional view in elevation of an adjustable steam chest in accordance with the invention.

Referring now to Figure 1 there is shown a fluidized bed gasifier (or reactor) 10 in accordance with the state of the art including a vessel 12. The vessel 12 is generally cylindrical, including an ash annulus 14 disposed in the lower portion of the vessel 12, a combustion section 16 disposed in the upper portion of the vessel 12, an inlet feed system 18 disposed through the vessel 12 and upward through the ash annulus 14, an ash outlet 20 at the bottom of the ash annulus 14, a starwheel feeder lockhopper 21 below the ash outlet 20, and a product gas outlet 22 at the top of the vessel 12. Disposed within and near the bottom of the ash annulus 14 is a sparger ring 28. The feed inlet system 18 further comprises an outer concentric tube 30 extending partially up the length of the feed inlet system 18 near the top of which are outlets 32.

Carbonaceous material particles and other process mediums enter the vessel 12 through the feed system 18 forming a recirculating fluidized bed 24 wherein the particles are partially combusted with oxygen, and partially gasified with steam, producing a combustible product gas and waste ash. Fluidizing and cooling gases are injected into the ash annulus 14 from the sparger ring 28 and the

outlets 32 in the outer concentric pipe 30. Typically, cleaned product gas or "recycle" gas is injected from the sparger ring 28 and steam is injected from the outlets 32.

During operation, the general flow path followed by the process mediums is upwardly in the center of the vessel 12 from the feed inlet system 18, into the bed 24 and downwardly from the bed 24 adjacent the walls of the vessel 12. Unless they are drawn back upwardly around the feed inlet system 18, particles of both agglomerated ash and char defluidize from the bed 24 into the ash annulus 14. This material is typically at a temperature of approximately 1800° or hotter. As the material defluidizes towards the ash outlet 20, it is cooled by the lower temperature gases injected into the ash annulus 14. These gases also serve first to promote agglomeration by cooling of the molten ash, and second to separate the char from the agglomerated ash. Because the char is much less dense than the agglomerated ash, it is more easily refluidized by the upward flow of the gases in the ash annulus 14. The density of agglomerated ash, however, is sufficiently high that the upward gas flow does not substantially refluidize the ash back into the fluidized bed 24.

The level of ash within the ash annulus 14, and hence the elevation of the char-ash interface, is determined by the difference in the rate of ash accumulation and the rate of ash withdrawal. The rate of ash accumulation is based primarily on the coal feed rate. All coal contains a percentage of ash compounds. While this percentage may vary between coal types, within a single type, it is relatively constant. Thus, the amount of ash fed to the gasifier 10

can be determined from the coal feed rate. The rate of ash withdrawal is governed primarily by the starwheel feeder 21. During steady-state operations, the two rates are equal and the level within the ash annulus 14 is constant. During periods of turn-up or turn-down (when the gasification reaction rate is increasing or decreasing, respectively) the ash withdrawal rate must be increased, or decreased, accordingly, in order to maintain a constant level within the ash annulus 14. If during steady-state operation it is desired to change the level of the ash within the ash annulus 14, this can be accomplished by varying the speed of the starwheel feeder 21.

Referring now to Figure 2 there is shown a fluidized bed gasifier (or reactor) 110 including a vessel 112. The vessel 112 is generally cylindrical, including an ash annulus 114 disposed in the lower portion of the vessel 112, a combustion section 116 disposed in the upper portion of the vessel 112, an inlet feed system 118 disposed through the vessel 112 and upwardly through the ash annulus 114, an ash outlet 120 at the bottom of the ash annulus 114, a starwheel lockhopper 121 below the ash outlet 120 and a product gas outlet 122 at the top of the vessel 112. Disposed in the ash annulus 114 above the ash outlet 120 is a source of fluidizing and cooling gas such as a sparger ring 128. Disposed around the feed tube 118 is a movable gas injection means, such as a steam chest 150, to which may be attached gas supply means, such as steam tubes 152, which may be disposed downwardly from the steam chest 150 through the ash annulus 114 and through the vessel 112. Around the steam tubes 152 at the vessel 112 penetration is tube packing 154.

In a manner similar to the state-of-the-art reactor shown in Figure 1, carbonaceous material particles and other process mediums enter the vessel 112 through feed system 118 forming a recirculating fluidized bed 124 wherein the particles are partially combusted with oxygen and partially gasified with steam producing a combustible product gas and waste ash. Fluidizing and cooling gases are injected into the ash annulus 114 from the sparger ring 128 and the steam chest 150. Typically, recycled gas is injected from the sparger ring 128 and steam is injected from the steam chest 150. The general flow path followed by the process mediums in the fluidized bed 124 is similar to the flow path of the process mediums in the bed 24 as discussed above with respect to the state-of-the-art reactor 10 in Figure 1. Similarly, the level of ash within the ash annulus 124 is controlled by the starwheel feeder 121 as discussed above with respect to the state-of-the-art gasifier in Figure 1.

Referring now to Figure 3, the steam chest 150 is shown in greater detail. The steam tubes 152 are attached to the steam chest 150, and steam inlet 156 provides flow communication between the steam tubes 152 and the steam chest 150. Steam outlet 158 provides flow communication between the steam chest 150 and the ash annulus section 114. Steam chest packing glands 160 prevent passage of steam from the steam chest 150 upwardly or downwardly around the inlet feed system 118.

The operation of the steam chest 150 is as follows. During operation of the gasifier 110, steam is conveyed through the steam tubes 152 through the steam inlets 156 and into the steam chest 150. The steam then passes out through the steam outlets 158 and into the

ash annulus 114. In the event process variations result in a desire to change the elevation of the char-ash interface, this change can be made by raising or lowering the steam chest 150 from a point external to the gasifier 110. The steam chest 150 is not affixed to the inlet feed system 118 but rather is free to slide up and down and still remain sealed as a result of the use of the packing glands 160. Further, the steam tubes 152, although fixed securely to the steam chest 150, are also free to move up and down through the ash annulus 114 as a result of the use of tube packing glands 154.

When the preferred level of ash within the annulus 114 is determined taking into consideration the factors set forth in the prior art, the level can be achieved using a method similar to that set forth in U.S. Patent No. 4,309,194. Upon achieving the desired ash level, the steam chest 150 is moved up or down by adjusting the steam tubes 152. In the preferred embodiment, the steam chest will be positioned at the ash level within the annulus. Operational experience indicates that the char-ash interface extends from the ash level to a point 304.8 mm to 457.2 mm above the ash level. Although this measurement is not definite, it has been determined that the interface will not be below the steam chest 150.

The desirability of changing the elevation of the steam chest 150 to accommodate different elevations of the fluidynamic char-ash interface stems from several considerations. The first consideration relates to the separation of the char from the agglomerated ash. During normal operation, agglomerated ash and char both tend to defluidize into the ash annulus 114. While most of the agglomerated ash defluidizes as a result of its greater density and

the inability of the inlet feed system 118 to keep it fluidized in the bed 124, the char defluidizes primarily as a result of flow path variations in the fluidized bed 124. Char and ash recirculating in the fluidized bed 124 flow downwardly adjacent the walls of the vessel 112. The operation of the inlet feed system 118 causes a general updraft from a region below the top of the inlet feed system 118 into the bed 124. This general updraft results in the refluidization of some amounts of char. If the char in its recirculation path in the bed 124 is not drawn back up into the bed 124, it will fall into the ash annulus 114. In either case, use of the steam chest 150 provides a fluidizing and separating means which is not associated with the inlet feed system 118 directly. The steam flow from the steam chest 150 is not sufficiently high to substantially refluidize the agglomerated ash, however, it will refluidize the char. If the steam chest 150 is at a high elevation, then the probability that any particular piece of char will be recirculated up into the bed 124 is high because of the short distance over which the steam flow momentum must act. The char is refluidized before re-entering the fluidized bed 124, i.e., from the steam chest 150 to the top of the inlet feed system 118. On the other hand, if the steam chest 150 is at a lower elevation, it has a longer distance over which to act. Accordingly, the greater this distance, the greater the probability that the steam flow momentum will be dissipated or the char will lose its fluidization momentum and the lower the probability that any individual char particle will be refluidized up into the fluidized bed 124.

A second consideration results from the behavior of fluidized beds. A fluidized bed can be conceived as a pot of boiling water. If the pot is heated evenly, small bubbles will form within the pot at numerous points where heat is being applied. The result of this is that the bubbling action of the water is fairly uniform. On the other hand, if all the heat is being added at one point, significantly large bubbles will form in the pot of water from this single point. The resulting bubbles will cause excessive local disruption of the water. Similarly, if a small amount of gas is injected from multiple locations into a fluidized bed, small bubbles will form which are not disruptive to the fluidization process. On the other hand, if all the gas that is required is injected from a single point, large bubbles will form and slugging may result. Frequent slugging of the fluidized bed could cause an upset condition and this is an undesirable consequence. As a result, placing the steam chest 150 at a low position in the ash annulus 114 very close to the sparger ring 128 is undesirable, except when a short upset recovery time is considered more important than good separation.

The advantages of this apparatus and method over the prior art result from the improved control of a system operator over the process taking place in the vessel 12 or 112. In a system in accordance with the prior art, without the injection of fluidizing and cooling gases into the ash annulus 14, the mixture leaving the ash annulus 14 through the ash outlet 20 would be a mixture of char and agglomerated ash. Somewhere in the ash annulus 14 there would be an ash level but the level would be characterized not by a difference in material but rather by the difference in the quantity of

material. In other words, above this level would be a falling mixture of ash and char, and below the level would be a mixture of ash and char resting on the material below it with the lowermost material resting on the starwheel lockhopper 21 just prior to withdrawal from the ash outlet 20. With the addition of fluidizing and cooling gases, and particularly the injection of a gas at the outer concentric tube 30, a char-ash interface may be formed which would result in the refluidization of char back into the combustion section 16. As a result of this separating function there is no longer a char-ash mixture being discharged from the ash outlet 20. Instead, there is a char-ash interface above the ash level which is characterized by a varying amount of char with a relatively constant amount of ash, and where typically the char is in the process of being refluidized, while the ash is defluidizing.

As can be seen in Figure 1, the outer concentric tube 30 is typically a fixed component and its height is determined during design and fixed during manufacturing. As a result, the ash level and the char-ash interface level must all be calculated during the original design. If there is any error in the design or if there is any significant variation in the feed material which would make a change in the ash level or the char-ash interface level desirable, it may well be necessary to remove the entire feed inlet system 18. In contrast, it is not necessary to take into account all the different types of coals and all the different types of operating conditions which may arise during the operation of a gasifier 110 in accordance with the invention. This provides significantly greater flexibility of the gasifier 110 during its life.

The gasifier system 110 operation may be optimized in the following manner. The rate of ash withdrawal from the ash outlet 120 is matched to the calculated ash feed rate based on the coal feed rate and ash content of the coal. When the two rates are matched, the temperature of the ash is determined as it is discharged. If this temperature is too hot, say at a temperature above 343°C it indicates that the ash has spent insufficient time in the ash annulus 114 to cool. As a result, it is necessary to increase the inventory of ash within the annulus 114. This is done by slowing the withdrawal rate until the temperature is within the desired range and then once again matching the ash withdrawal rate with the calculated ash feed rate to the gasifier 110.

At this time, the steam chest 150 should be at a relatively low elevation within the ash annulus. The material being discharged from the ash outlet 120 is analyzed to determine the total ash content. At the same time, a determination is made of the particle fluidization near the top of the feed inlet system 118. This determination may be made by reading differential pressure cells with pressure taps spaced at different elevations in the ash annulus 114. Other means are also acceptable. In an ideal situation there should be fairly constant readings at the bottom of the ash annulus 114. This indicates that there is little or no fluidization at the bottom of the ash annulus 114. As higher elevation differential pressure cells are read, they should indicate more and more agitation by fluctuating differential pressure. Ideally, there should be a maximum amount of agitation near the top of the feed inlet system 114. This indicates a maximum amount of fluidization near the top of

the feed inlet system 118 at the bottom of the fluidized bed 124. This indicates that the char-ash mixture at the bottom of the bed 124 is being sufficiently agitated to refluidize substantially all of the char. If this is not the case, the steam chest 150 is moved up in elevation. When the maximum amount of agitation is achieved, the ash content of the mixture discharged from the ash outlet 120 is again analyzed. It is also examined visually to determine any amount of sintering. If the steam chest 150 is at an elevation sufficiently high to result in refluidization of agglomerated ash, it will result in ash being returned to a molten state in the combustion section 116 and this in turn will result in larger particles of ash. As the ash particles are increased in size, there is a greater possibility of disruption or blockage of the ash outlet 120 or the starwheel lockhopper 121 below the ash outlet 120. This is undesirable and if it begins to occur the steam chest 150 is moved down until sintering of the ash has been reduced to an acceptable level. At this point in time, the elevation of the steam chest 150 has been optimized.

What is claimed is:

1. A process for optimizing the ash separation and cooling operation of a fluidized bed gasifier which produces a mixture of ash and char from a carbonaceous material, comprising the steps of:

(A) feeding said carbonaceous material to said gasifier at a first rate,

(B) discharging said mixture from said gasifier at a second rate approximately equal to a rate of introduction of ash contained in said carbonaceous material fed into said gasifier in step (A),

(C) maintaining the discharge temperature of said mixture below a temperature T,

(D) injecting a first gas at a first elevation within said gasifier,

(E) injecting a second gas at a second elevation which is above said first elevation to refluidize a portion of said mixture,

(F) measuring the ash content of the discharged mixture,

(G) measuring sintering of ash of the discharged mixture, characterized by the further steps of

(H) raising said second gas injection elevation to increase said ash content or lowering said second gas injection elevation to reduce sintering of said discharged ash, and

(I) repeating steps (E) through (H) until both ash content and sintering of ash of said discharged mixture is acceptable.

2. A process in accordance with claim 1 wherein said temperature T is 343°C.

3. A fluidized bed gasification reactor (110) comprising a generally cylindrical vessel (112), an ash annulus section (114) disposed in a lower portion of said vessel, a combustion section (116) disposed in an upper portion of said vessel, an inlet feed tube (118) disposed through said vessel and upwardly through said ash annulus section, an ash outlet (120) at the bottom of said ash annulus, a product gas outlet (122) at the top of said vessel, characterized by a movable gas injection chest (150) disposed around said feed tube, and a gas tube (152) attached to said steam chest at an end of said tube, and disposed downwardly from said gas injection chest through said ash annulus and through said vessel.

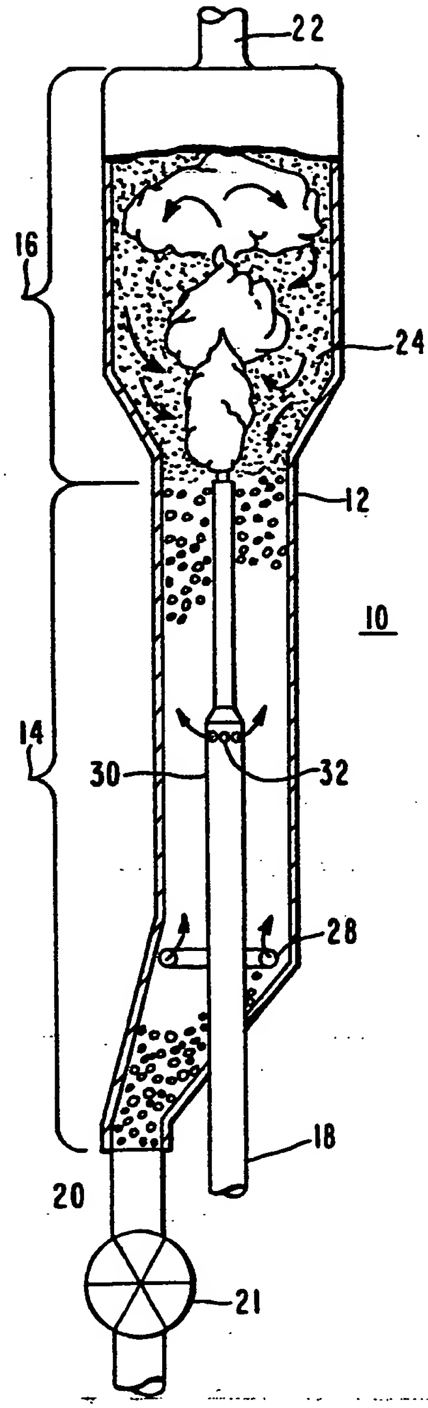
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FIG. 1

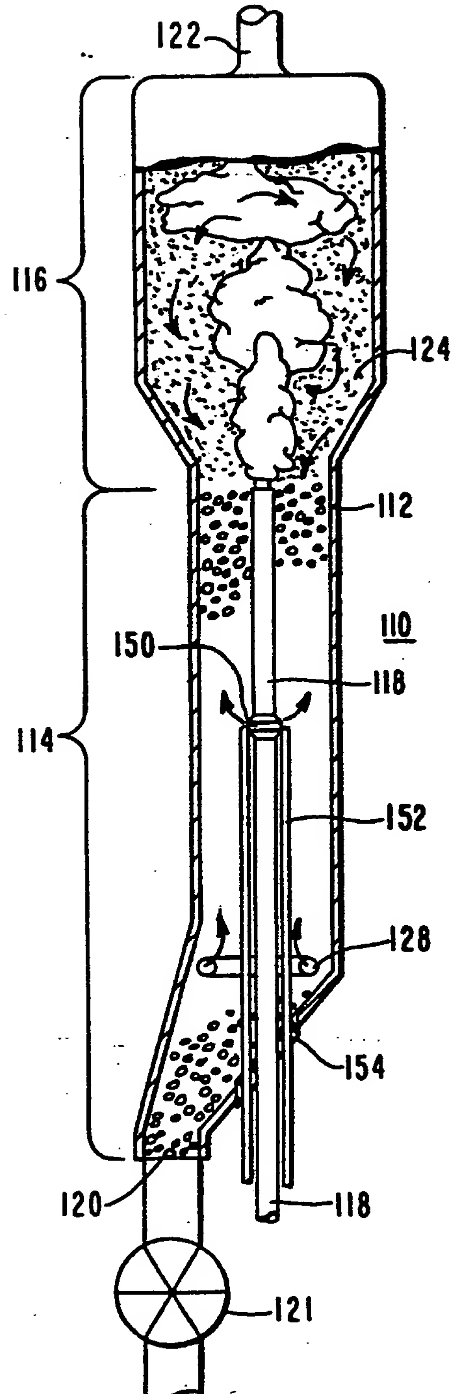
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FIG. 2

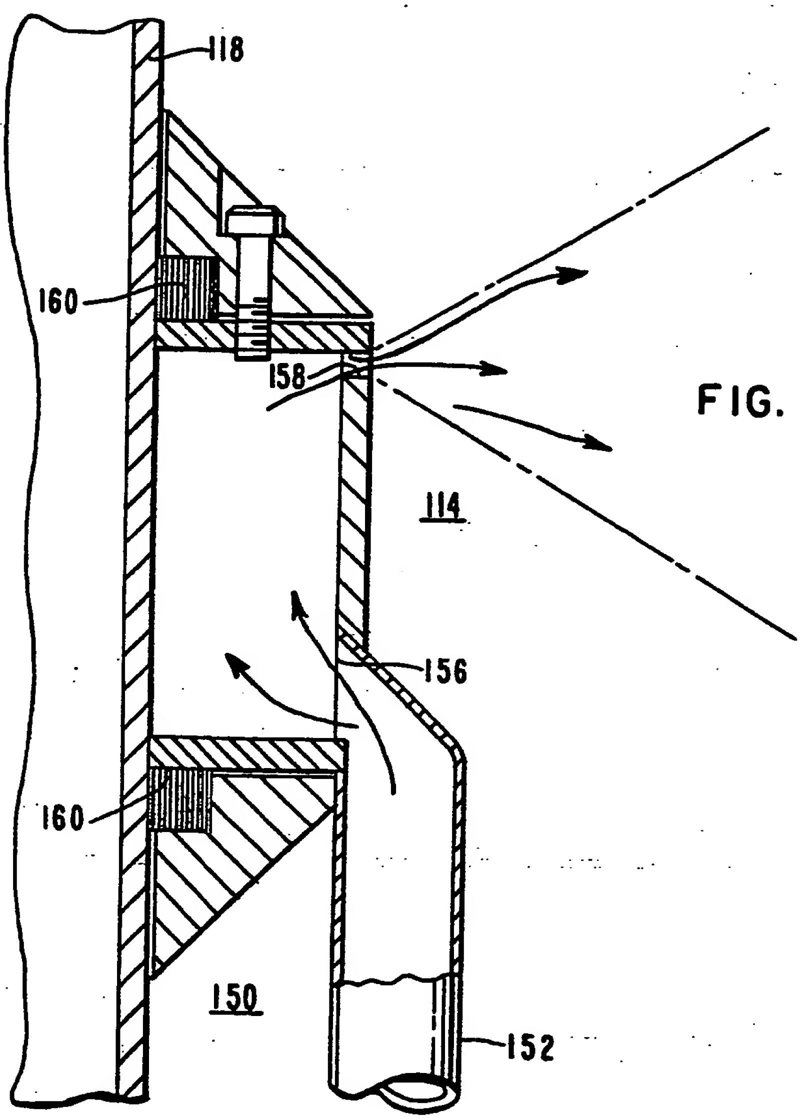

FIG. 3